DEVELOPMENT OF A HUMANLIKE PELVIS FOR A MID-SIZED MALE SIDE IMPACT DUMMY

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OBJECTIVES OF THE RESEARCH

This research was conducted in the frame of the WorldSID [1] and the SID 2000 [2] projects. The objective was to develop a physical representation of the human pelvis that meets the requirements for a mid-sized male side impact crash test dummy acceptable for worldwide harmonisation. Compared to existing dummy designs, the pelvis should better reflect the actual human being in terms of anthropometry and dynamic behaviour in lateral loading conditions. It should also offer enhanced injury assessment capabilities and durability.

METHODOLOGY

Based on different existing anthropometrical data sources, the pelvis concept development started from the analysis of the EUROSID-1 behaviour with respect to that of the human pelvis. Human finite element modelling and dummy multi-body models were used to quantify load paths and magnitudes in order to design the new dummy pelvis and its instrumentation.

In a first approach, the new pelvis concept was proposed based on the requirements described in the ISO document TR 9790 [3] and on recent published data on post mortem human surrogates [4]. Force deflection analyses of the PHMS' and the EuroSID-1 pelvis under lateral impact conditions have learned that the force deflection characteristics of a human and the dummy pelvis are different (figure 1).

More precisely, it was observed in impactor tests that the PMHS' impact force increases gradually from the beginning of the impact, whereas the dummy force response stays low. It was concluded that, in the case of PMHS tests, when the greater trochanter is struck, the force is increased due to the leg inertia. On the contrary, in the tests performed on the dummy, very little increase in force is noted at impact corresponding only to the flesh foam compression without contribution of the leg mass. When the flesh foam is completely compressed (bottomed out) and the impactor contacts the pelvic internal rigid parts, a rapid increase of the impactor force is created (figure 1). In that way, the analysis of the human and the current EUROSID-1 has permitted a better understanding of the main requirements in terms of the dummy pelvis design. Impactor tests on an experimental dummy pelvis (developed by INRETS, Figure 2), where a flexible internal structure on which legs were attached, has shown that this analysis was consistent. A similar increase of the impact force was observed with this experimental concept as in PMHS tests (Figure 2).

The second step was to specify the anthropomorphic requirements in terms of external shape and internal bone dimension. The UMTRI [5] data set for a 50th percentile male in a sitting position was chosen as the dimensional basis for the WorldSID dummy [6]. Concerning the internal pelvic, however, the Reynolds [7] data are the most complete. For the dummy, only a few anatomical points must be reproduced such as anterior superior iliac spine, iliocristale summum, pubic symphysis, pubotuberosities, S1, promotorion. These are mainly inferior and superior points on the pelvic bones that affect the interaction with the seat or the abdomen. Concerning the femur, the position of the greater trochanter was calculated using anatomical angles of the femur neck [8] and bi-trochanter width

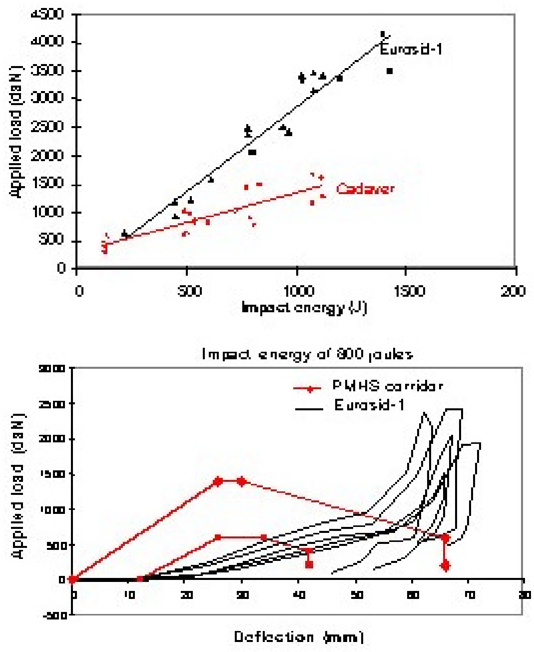

Figure 1: Comparison of PMHS and EUROSID-1 applied loads (top) and force/deflection [4].

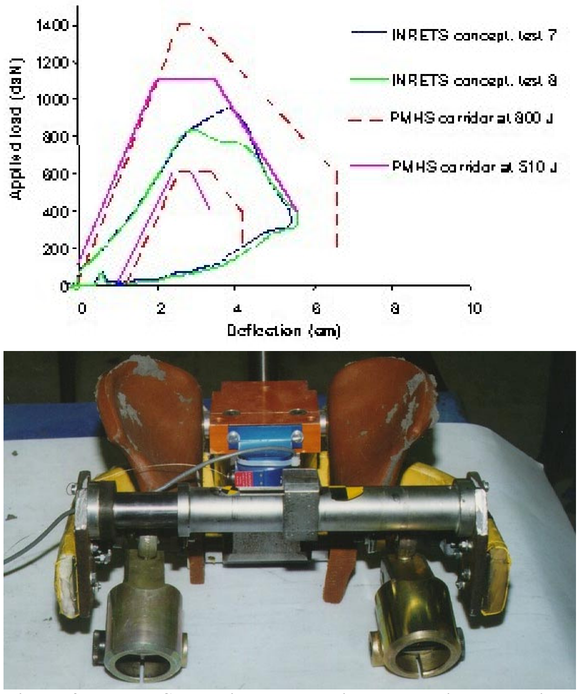

Figure 2: INRETS experimental pelvis response in comparison with PMHS corridor by Bouquet et al. [4].

measured by UMTRI with flesh compressed.

HUMAN MODELLING

In order to understand the biomechanics of the pelvic region, a finite element model of the human pelvis was used to provide information on the load paths that occur within the pelvic region under automotive side impact loading.

The human pelvis model had initially been developed by TRL, independently of the surrounding anatomy. The model included biofidelic representation of the sacroiliac joints and the pubic symphysis, as well as the hip joint. The model was validated against published test data carried out on human pelves loaded laterally with one side embedded in cement [9]. Once validated, the model was incorporated into a full body model, that comprised a combination of Hybrid III dummy parts and human components (namely a human spine, neck and legs, Figure 5). The posture of the combined model was fitted to the UMTRI data being used as a standard within the WorldSID programme. Having incorporated the pelvis into the full human model, validation was carried out against dynamic cadaver tests, where cadavers were struck at the greater trochanter [4] (figure 3 *(note bottom figure: rough data, offset due to the imprecision of the contact between the PMHS' clothes and the impactor plate)*).

Once the pelvis model was complete and validated, it could be used in the study of load paths from the impact point on the pelvis through to the reactions, which would largely be inertial but also distributed throughout the body. An initial area requiring the use of the model was the distribution of side impact loads between internal load paths within the body. The Figure 4 provides an example of load path analysis for one loading condition. The model was also used to predict fractures, and these were found in similar locations to those observed following the PHMS tests, with fractures mainly at the pubic rami (figure 5). For the more severe tests additional fractures were found at the iliac wing, the sacro-iliac articulation, the femur and the cotyle.

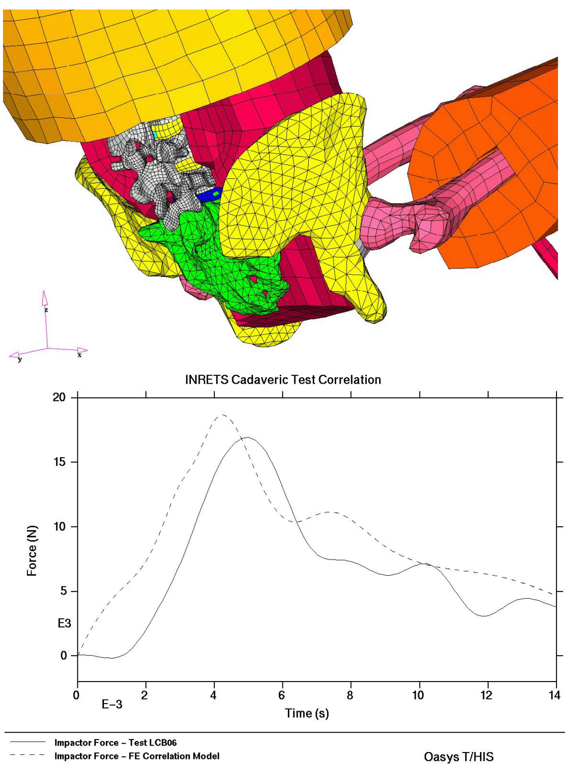

Figure 5: Top: Detail of pelvic area in full-body model. Bottom: Impactor force correlation using INRETS test data (1100J impact).

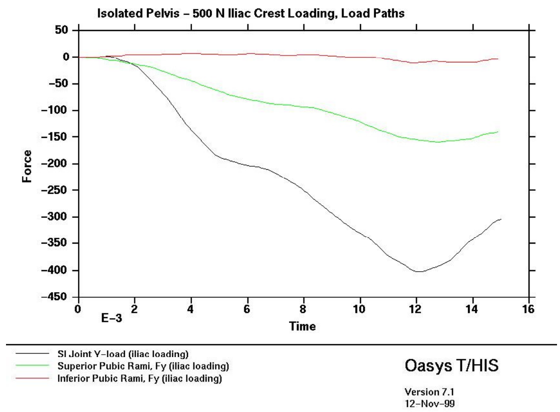

Figure 4: Load distribution between pelvic load-paths

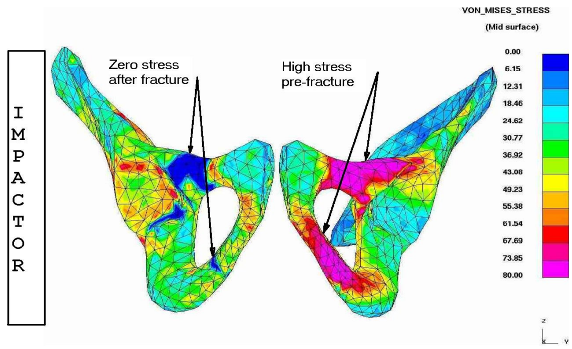

Figure 3: Pelvic stress distribution indicating fracture of pubic rami.

These injuries are not reproduced in the model.

DEVELOPMENT

The pelvis prototype was designed, engineered and build by TNO in co-operation with WorldSID Design Team members DTS, Endevco, FTSS and R.A.Denton. Besides biomechanical and anthropomorphic requirements, the design of the new pelvis needed response tuning and load detecting capability.

Stiffness of bone and flesh representing parts were selected as parameters to tune the pelvis response in the final prototype. To avoid any hidden load path, all possible load paths through the pelvis were identified. Subsequently, load cells were positioned at these strategic points. The greater trochanter and the iliocristale were identified as the most lateral positioned bone points and the entry of the external applied forces. Internally, the forces are distributed between the pubic symphysis and the sacroiliac joint, passing to the lumbar spine through the sacrum. Therefore, a femoral neck load cell (LC), a pubic LC, a sacroiliac LC and a lumbar spine LC are available in the pelvis.

Building, validating and analysing a hybrid multibody-FE model of the pelvis concept further supported the design process. The multibody/FE model was validated against two pendulum impact conditions of 135 J (3.4 m/s, non-injurious) and 510 J (6.6 m/s, injurious). Stiffness of bone and flesh representing parts and target capacities of the load cells were gained thanks to a parametric study (Figure 6).

Because of the limited space in this area, the WorldSID pelvis internal structure became a complex design. Integrated in the central structure are: one 6 channel lumbar spine load cell, two 6 channel Iliac wing load cells, two tilt sensors, one triaxial accelerometer, an amplification unit, all connecting to an internal 32 channel Data Acquisition System (DAS). A major design effort was dedicated to

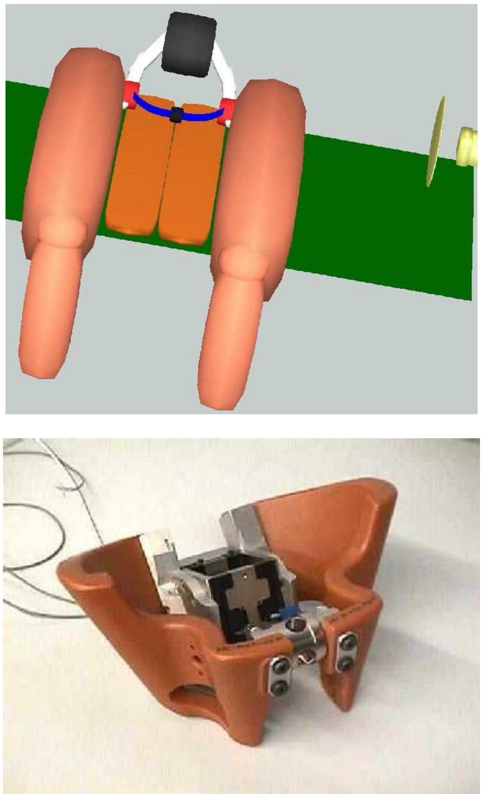

Figure 6: Top: Simplified multibody/FE pelvis model
Bottom: WorldSID prototype pelvis internal structure.

integrate the femoral neck load cell, the greater trochanter representation and issues related to part manufacturing and mould construction for the proximal upper leg flesh.

The complete design was modelled using state-of-the-art 3D CAD systems. This allowed WorldSID Design Team members working all over the world on the integrated design, to share and exchange models using the STEP data exchange protocol.

VALIDATION

The first evaluations performed on the WorldSID prototype show that the trend is in good correspondence with the PHMS test results for the 135 J (3.4 m/s) and the 510 J (6.6 m/s (figure 7)) pendulum impacts, in the sense that the force builds up right form the beginning of the test, with a peak force before 10 ms after impact and then drops off to zero between 20 and 30 ms. Figure 7 also indicates that the WorldSID pelvis is tuneable to some extent.

CONCLUSION

The WorldSID prototype pelvis design is close to the human in terms of shape, structure and mass distribution. It includes measurement capabilities in sacroiliac area, pubic symphysis and femoral neck regions, preventing any hidden load paths. Also the handling of the dummy was improved in comparison with the existing dummies. The instrumentation was made easily accessible, the dummy positioning reproducible with the use of the two tilt sensors and the assembly and disassembly were simplified. This approach consisting of combining the results of anthropometry and biomechanical review, human body and dummy simulations, Computer Aided Design and Engineering is unique in the area of crash dummy development.

The new pelvis is part of the harmonised biofidelic advanced mid-size male WorldSID dummy prototype, which is currently undergoing a number of evaluations in particular with respect to biofidelity in North-America.

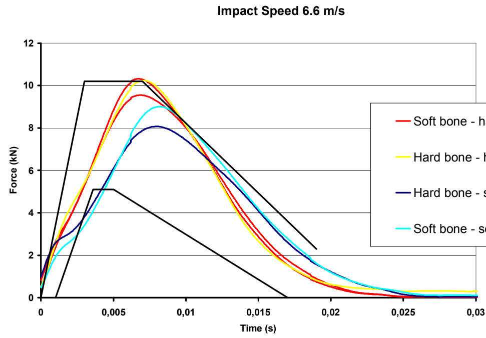

Figure 7: WorldSID prototype pelvis response (510 J impact) obtained with various combinations of parts (tests performed with pelvis and legs only).

Further evaluations will be conducted in the frame of the European SIBER project, which is the European contribution to the global effort for the development of the WorldSID pre-production version [10].

ACKNOWLEDGEMENTS

For their contribution to this work, the authors thank the following organisations and persons:

European Commission Framework IV project SID2000, Contract CT98 0621,

WorldSID Task Group,

WorldSID Design Team - Biokinetics, Denton ATD, DTS, Endevco, FTSS, INRETS, R.A. Denton, TNO, TRL.

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